THE COMPARATIVE STUDY OF DRIVETRAIN OF HIGH-PERFORMANCE ELECTRIC VEHICLE

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Summary

When constructing the electric vehicle for the Shell Eco-marathon competition in Urban Concept category , the Smart Power Team had to face the problem of choosing the perfect drivetrain. For this purpose, two bests concepts were studied. The first concept assumed the use of high-speed BLDC motor along with belt transmission with toothed belt. The second concept assumed the low-speed BLDC hub motor. The research was conducted for the MuSHELLka vehicle on the roller dynamometer. The aim of the research was to compare both concepts. The main selection criterion was the performance of both systems, measured at constant load and speed range of 0-30 km/h. The measurements were carried using the National Instruments hardware and software devices, the analysis of the results was performed in MATLAB software. This article includes the accurate description of the measuring circuit, the course of the research, data analysis and conclusions.

Keywords: BLDC motor, Shell Eco-marathon, efficiency, electric race car, roller dynamometer

BADANIA PORÓWNAWCZE UKŁADÓW NAPĘDOWYCH WYSOKOSPRAWNEGO POJAZDU ELEKTRYCZNEGO

Streszczenie

W trakcie projektowania elektrycznego bolidu startującego w zawodach Shell Eco-marathon w kategorii Urban Concept zespół Smart Power napotkał problem wyboru najlepszego napędu. Z wielu możliwych opcji zostały wstępnie wybrane dwa rozwiązania. Pierwsze zakładało zastosowanie szybkoobrotowego silnika BLDC z przekładnią z płaskim pasem zębatym. Drugie rozwiązanie zakładało zastosowanie wolnoobrotowego silnika BLDC zabudowanego w piaście. Do ostatecznego wyboru rozwiązania konstrukcyjnego zdecydowano się na dokonanie badań na stanowisku badawczym obejmującym hamownię podwoziową opracowana specjalnie do tych celów. Badanie obejmowało identyfikacje rzeczywistych osiągów napędów w całym zakresie prędkości roboczych 0-30 km/h. Pomiarów dokonano z zastosowaniem aparatury pomiarowej National Instruments natomiast analizę wyników wykonano w środowisku oprogramowania MATLAB. W artykule opisano szczegółowo tor pomiarowy, plan i przebieg badań oraz wyniki analizy danych wraz z ostatecznymi wnioskami.

Słowa kluczowe: silnik BLDC, Shell Eco-marathon, sprawność, bolid elektryczny, hamownia podwoziowa

INTRODUCTION

Nowadays we can observe the constant growth of the pressure put on the ecology and environmental protection aspects. Pro-ecological solutions can be seen in every aspect of our daily lives. One of the bests examples to confirm that is automotive industry. Each of the biggest producers offers its customers electric or at least electrically assisted cars. Significant decrease of operating costs, better and better operating parameters and rather small negative impact on environment are the reasons for constantly growing popularity of these solutions. The need to promote ecological vehicles was noticed by the Shell group. This resulted in organizing the Shell Eco-marathon (SEM) competition [9], which gathers students from all over the world. The main aim of this competition is to travel certain distance using as little energy as possible. Students participate with vehicles designed and built by themselves. There are many categories depending on what kind of fuel is used and what kind of car the vehicle is (either prototype or urban car).

The Smart Power Team [10] which works at the Faculty of Mechanical Engineering of Silesian University of Technology is currently building and modernizing two electric vehicles [6, 8], designed especially for the Shell Eco-marathon. The first one is MuSHELLka – a prototype vehicle, which has already been successfully classified in two SEM events – SEM 2012 and SEM 2013. It can be characterized best by very small dimensions and extremely low weight. The other car, Bytel, is the

urban vehicle. This means that it resembles a small single car, like the ones that we can see on streets on a daily basis. What differs urban cars from prototypes is the obligatory equipment needed to travel through the city safely.

Figure 1 Render of Bytel vehicle

THE CHOICE OF RESEARCHED DRIVETRAINS

The research described in this article concerns the performance of the drive systems used in high-performance electric vehicles. There were two concepts studied. The concepts were chosen on a basis of assumed motion parameters of the vehicle, detailed analysis of motors available on the market and experience of the Smart Power Team.

The following basic vehicle parameters are expected:
- CX coefficient: 0,3;
- frontal area: 1,06 m^2;
- rolling resistance: 15 N/ 1000 kg ;
- vehicle weight: 200 kg with the driver;
- wheel radius: 0,279 m.

Motion parameters for vehicle during Shell Eco-marathon competition:
- number of laps: 10;
- lap length: 1630 m;
- one obligatory stop during each lap;
- travel speed: 28,76 km/h;
- time to reach the travel speed: 30 s.

For the calculation performed to help with elements selection such as electric motor and gear, the classical approach was taken, which is known from theory of vehicle movement [2, 8]. Based on this approach, in order to achieve the desired motion parameters, it is necessary to assure that the propeller is higher than total resistance force acting on a moving vehicle [3, 5].

Total resistance force is equal to 68.71 N, having the wheel radius equal to 0.279 m, we calculate the torque which equals to 19.17 Nm.

The urban vehicle will be equipped with two identical drive systems placed one the rear axis. Taking that into consideration the torque of each one of them has to be greater than 9.585 Nm.

For detailed research the following systems were chosen:

The first system (Fig. 2) consists of high-speed BLDC motor Dunkermotoren BG75x50 [11] working with high-performance belt gear with toothed belt with the ratio equal to 7.14. The gear transmits the torque to the wheel with freewheel.

Figure 2 High-speed BLDC motor Dunkermotoren BG75x50 drive system

The second system (Fig. 3.) consists of low-speed, gearless BLDC hub motor Magic Pie 3 [12].

Figure 3 Low-speed, gearless BLDC hub motor Magic Pie 3 drive system

Drive systems that were chosen provide different approaches to construct electric vehicle drivetrain and represent possibly the best solutions in their class.

Table 1.: Motors parameters comparision

Parameter	Dunkenmotoren	MagicPie3

	BG75x50	
Rated power supply voltage	40V	48V
Rated speed	3500 rpm	350
Rated torque	1,1 Nm	20Nm
Rated current	12A	15A
Motor weight	2,2kg	11kg
Power	480W	520W

While starting the research our knowledge about the chosen motors was not enough to make a decision about which one of them will be better to implement in high-performance electric vehicle. The Dunkenmotoren motor BG75x50 was used in previous Shell Eco-marathons however, data of the performance of the entire drivetrain was missing. Previous studies have included only the engine itself without the whole powertrain.

It was the first time that Smart Power team had to deal with hub motor, and the data provided by manufacturer was rather inaccurate due to wide voltage and current range in which the motor could work properly. Also characteristics provided by the manufacturer does not satisfy our needs, as it covers the rotational speed range of 280-360 rpm. Because of the obligatory full stop during each one of 10 laps drives during the competition, in order to choose the drive system properly, it is necessary to know the characteristics in full rotational speed range.

The aim of this research was to compare the two drive systems described above, designate their performance in the domain of speed at constant load and designate their performance map. Knowledge of that data is crucial, because of the strong influence that the drive systems performance has on the result achieved during the competition.

ASSUMPTION DATA

- the research was conducted using roller dynamometer with one roll
- for research purposes MuSHELLka vehicle was used
- during the research there was a driver in a vehicle
- tires used during the data acquisition: Michelin 45-75 R16, were designed especially for Shell Eco-marathon competition
- tire pressure: 5 bar
- range of speed: 0-30 km/h
- drive systems running on battery LiFePo4 48[V] 10[Ah]
- both motors operated with the same controller

- the controller was triggered by signal from I/O device
- software for data acquisition written in LabVIEW
- data sampling frequency: 2048 Hz
- analysis and processing of the recorded data done in MATLAB

RESEARCH PLAN

1. calibration of the measurement system
2. preparation of the drive system
3. setting resistance to 9 Nm, taking three measurements
4. repeating point 3. for resistance: 8 Nm, 6 Nm, 4 Nm, 2 Nm
5. changing the drive system
6. repeating points 1-4
7. processing and analysis of recorded data

Each measurement is initiated from the level of acquisition software. The data was recorded until speed stabilization, after this moment the data acquisition was terminated and the drivetrain was stopped. For further analysis there was only the data corresponding to the speed value of the vehicle – 0-30 km/h (0-333 rpm of the wheel) taken into consideration.

RESEARCH STAND DESCRIPTION

The research stand, where the measurements were conducted, was the roller dynamometer with one roll. It was assumed that the measurements on the test will take place in a completely automated. The load is automatically set by the brake for the full scope of each of the propulsion system [4]. Data from BLDC motors will be collected in order to allow further complete analysis [1, 7].The stand scheme can be seen on Fig. 4.
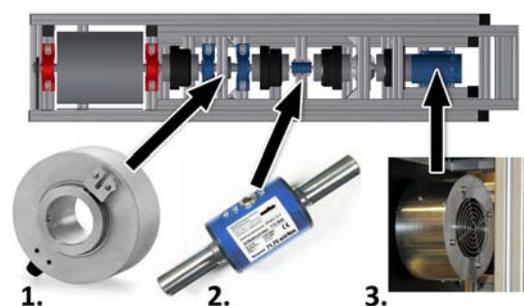
Figure 4 Research stand (1. Encoder 2. Measuring shaft 3. Electromagnetic brake)

The research stand consisted of the following elements:

Rotational speed was measured with encoder Lika C80. The encoder is an incremental encoder with 2048 pulses per revolution. The maximum speed,

that can be measured equals 6000 rpm. Acquisition of the data from the encoder was conducted via rapid digital module NI9401 at speed of 100 ns.

Torque on the shaft was measured with magnetostrictive torque sensor NCTE 2000 series of nominal torque equal to 17.5 Nm. It enables measurement in both directions of the shaft rotation at speed up to 5000 rpm. The sensor is of a first class precision. The manufacturer ensures high sensor tolerance to dynamic load. Analog response of the sensor equals 140 mV/Nm and was recorded via 16-bit analog to digital NI9215 device.

The torque on the shaft was forced by electromagnetic powder brake connected to a dedicated controller. The brake has a possibility of smooth adjustment of braking torque in a range of 0.3-12 Nm. The torque characteristics as a function of current is maintained to an accuracy of 5%, regardless of rotational speed and whether the current rises or falls. Brake control signal was transmitted from the analog outputs NI9263 device.

For the purpose of measuring the current, the ACS709 sensor was used. The sensor uses the Hall effect. Its measuring range is -37.5 - +37.5 A and its measurement error is no greater than 2%. The analog response of the sensor is 28 mV/A and it is recorded via 16-bit analog to digital NI9215 device.

The diagram of the measurement circuit can be seen on Fig. 5.
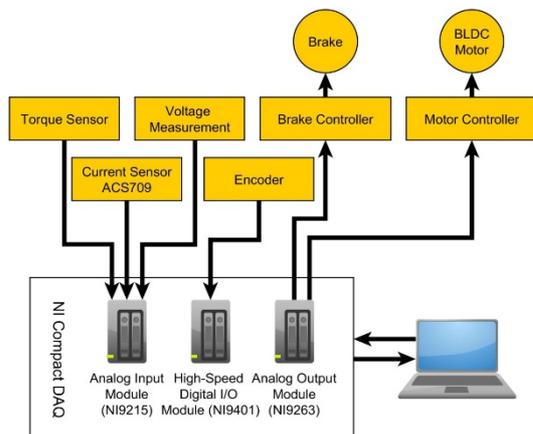
Figure 5 Diagram of measurement circuit.

SIGNAL ANALYSIS

Measurements were performed according to the previously described order. Each measurement was written to XLS file and then loaded to MATLAB software. After conversion of measured values to basic units and filtration of the signal with low-pass finite impulse response digital filter at cut-off

frequency of 10 Hz, the following values were calculated:

mechanical power:
$$P_m = M[Nm]*N[Rad/s]$$

electric power:
$$P_e = I[A]*U[V]$$

system efficiency:
$$S_{pr} = (P_m/P_e)*100\%$$

where:
M – torque of the motor
N – rotational speed of the motor
I – current drawn by the system
U – supply voltage
The next step was polynomial approximation of the results. The obtained plots can be seen on Fig. 6 and 7.
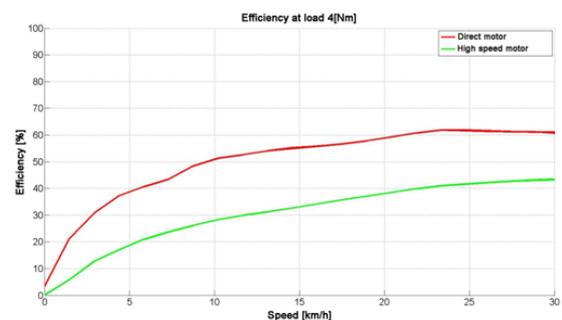
Figure 6 Efficiency diagram at load of 4 Nm.
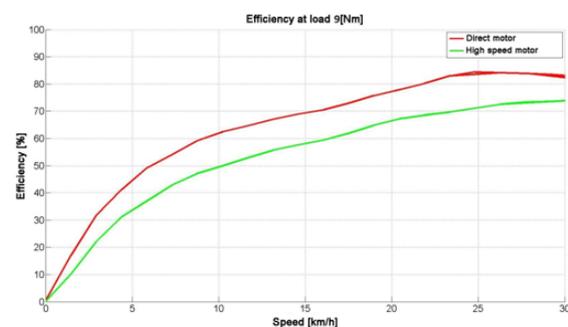
Figure 7 Efficiency diagram at load of 9 Nm.

The last step was to map the performance for the entire measuring range. Function gridfit, used for multiple regression, was used for this purpose. The data was approximated by a surface, which is shown on Fig. 8, as an isoline graph.

CONCLUSION

– Performance of the hub motor is better in the entire range of rotational speed measurements
– When making the final decision regarding which drive system to choose, it is necessary to take into account rolling resistance and total weight of systems

– Using hub motor greatly simplifies the design of the drive system
– Using hub motor enables regenerative braking system
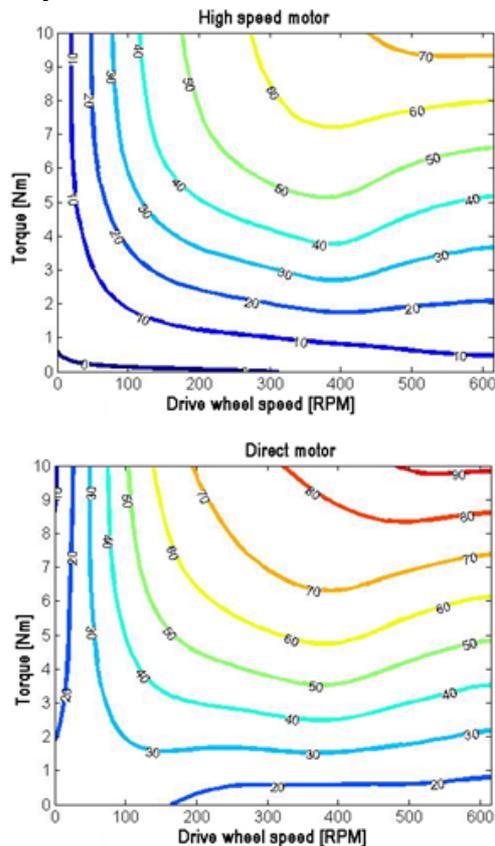
Figure 8 Efficiency map for high-speed and low-speed motor

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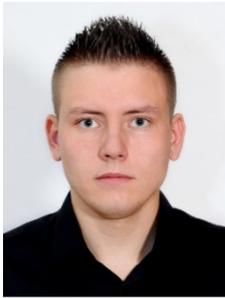
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